Tungsten the plasma facing material for a future fusion reactor!?

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TRILATERAL EUREGIO CLUSTER

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OVERVIEW - SUMMARY

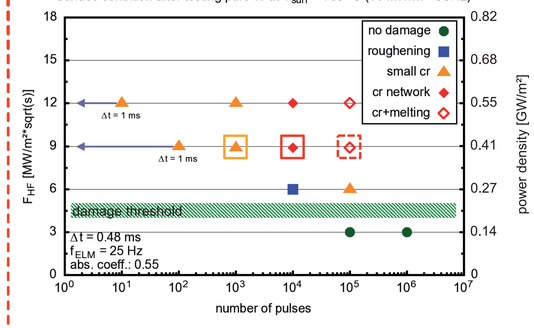
Tungsten (W) is the presently proposed material for the ITER Divertor and the whole first wall in DEMO. This is due to the high sputtering threshold of W, the low tritium retention, a high melting point and the comparably low level of neutron activation. However, metallic PFCs and in particular W as a high-Z element pose additional constraints for the operation of a fusion plasma. Recent experience with tungsten in TEXTOR and ASDEX Upgrade shows that melting can strogly influence the plasma performance and thus consequent avoidance of possible melting is a prerequisite for a reliable operation of a fusion device. Strong efforts are required to study its behaviour in more detail including behavior under transient thermal loads, thermal cycling, and real tokamak exposure evaluating potentially harmful material damage and structural changes. Despite these properties of tungsten, it remains the most promising candidate as first wall material for future fusion application.

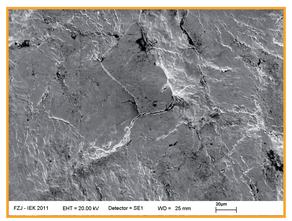
HIGH CYCLIC THEMAL SHOCKS

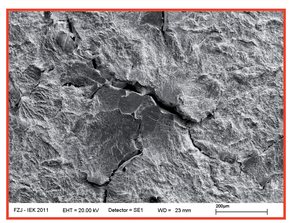
Material

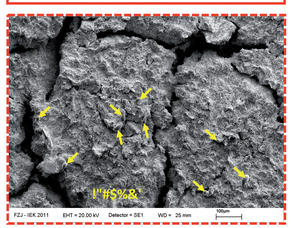
double forged tungsten
grain shape: **anisotropic**
testing orientation: **deformation parallel to surface**

Surface condition after testing pure W at T_{surf} ≈ 700 °C (10 MW/m^2 SSHL)









Thermal fatigue induced crack formation

Judith Electron Beam Facility Tests

THERMAL VARIATION

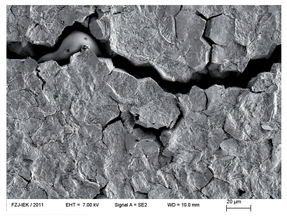
Testing parameters

number of pulses = 10^2 and **10^3**
Δt = 1 ms, f_{ELM} = 0.33 Hz, *abs. coeff.* = 0.55
power density = 0.38 GW/m²
F_{HF} = **12 MW/m²*s$^{1/2}$**
T_{surf} = **200**, 400, **700** and 1000 °C

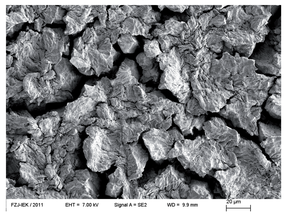
Material

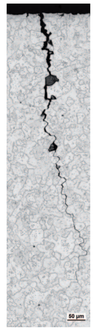
metal injection molded tungsten
grain shape: **isotropic**

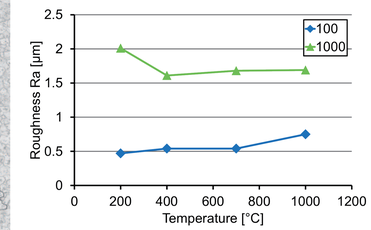
T_{surf} = 200 °C, n = 10^3

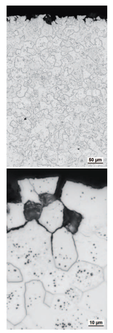


T_{surf} = 700 °C, n = 10^3









HIGH END MATERIALS

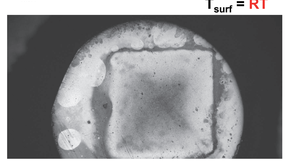
Testing parameters (A)

number of pulses = 10^2
Δt = 1 ms, f_{ELM} = 0.33 Hz, *abs. coeff.* = 0.55
power density = 1.13 GW/m²
F_{HF} = **36 MW/m²*s$^{1/2}$**
T_{surf} = RT and 100 °C

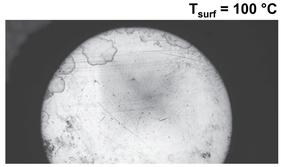
Material

toughness enhanced, fine grained W-1.1%TiC in the recrystallized state
grain shape: **isotropic**

T_{surf} = RT



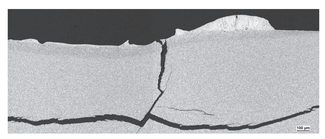
T_{surf} = 100 °C



No crack formation & no surface roughening (n=100)

Testing parameters (B)

number of pulses = 10
Δt = 5 ms, f_{ELM} = 0.33 Hz, *abs.* = 0.55
power density = 1.13 GW/m²
F_{HF} = **80 MW/m²*s$^{1/2}$**
T_{surf} = RT



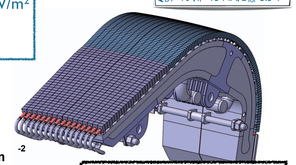
Melt formation causes tungsten purification & recrystallization

TOKAMAK CONDITIONS

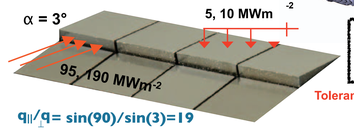
ITER

Steady-state heat loads $q_{\perp}$~ 10-20 MW/m²
Transient heat loads ~ GW/m²
τ_{ms}~0.5 ms, 2.1 MJ/m²
Disruptions: τ_{ms}~2.5 ms , >2 MJ/m²

ITER Standard Scenario
Q_{DT}=10 , I_P=15 MA, B_{TF}=5.3 T



STEADY STATE



~200.000 Tungsten Monoblocks

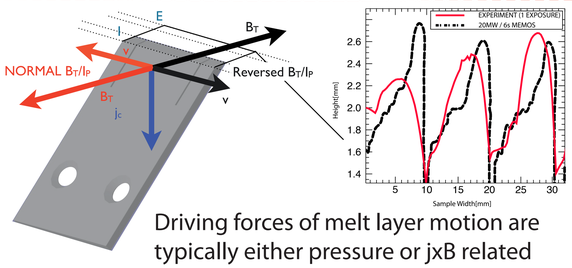
Tolerances: Neighbouring blocks < 0.3mm

$q_{||}/q_{\perp}$= sin(90)/sin(3)=19

Monoblocks can tolerate 0.3

TRANSIENTS Unmitigated ITER ELMs will damage monoblock edges and front surfaces

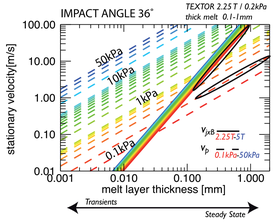
MELTLAYER MOTION



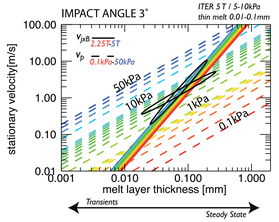
Driving forces of melt layer motion are typically either pressure or jxB related

Steady State melting suffers from jxB forces due to thermoelectric emission, while transient events are euqlly prone to both pressure and jxB

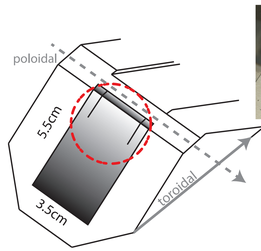
TEXTOR

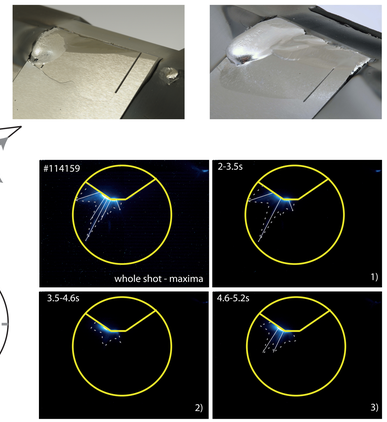


ITER

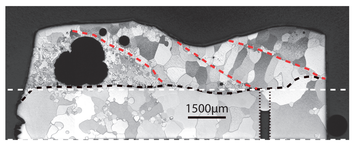


TOKAMAK MELT EXPOSURES





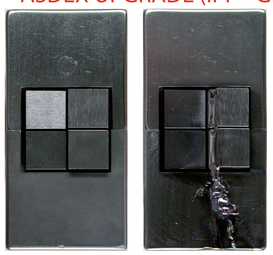
Apart from melt layer motion, spraying and splashing, macroscopic melt layer loss is occuring



Strong changes in grain structure and material distribution are apparent

ASDEX UPGRADE (IPP - GER)

Melting experiment in several tokamaks show similar issues:
Severe limitation of the operational space with damages of divertor High-Z components



Melt damage needs to be studied at multiple machines as self amelioration so far has not been observed